Chapter 9

The James Estuary Case Study

Figure 9-1 highlights the location of the James estuary case study watershed (catalog units) identified as one of the urban-industrial waterways affected by severe water pollution problems during the 1950s and 1960s (see Table 4-2). The James River basin, at the southern boundary of the Mid-Atlantic Basin, is one of the most important water resources in the Commonwealth of Virginia (Figure 9-2).

As the largest river in the state, the James River extends more than 400 miles from its mouth at the Chesapeake Bay to its headwaters near the West Virginia state line. The river is a recognized asset to the surrounding residential and metropolitan areas, providing recreational opportunities such as boating and fishing.

The James River is known for its annual national Bassmasters fishing tournaments, and it has exceptional Class IV white water rapids in the drop between the riverine and estuarine portions of the river in Richmond, Virginia. The river is also an asset to commerce and industry, serving as an important water supply and, as such, a catalyst for economic growth.

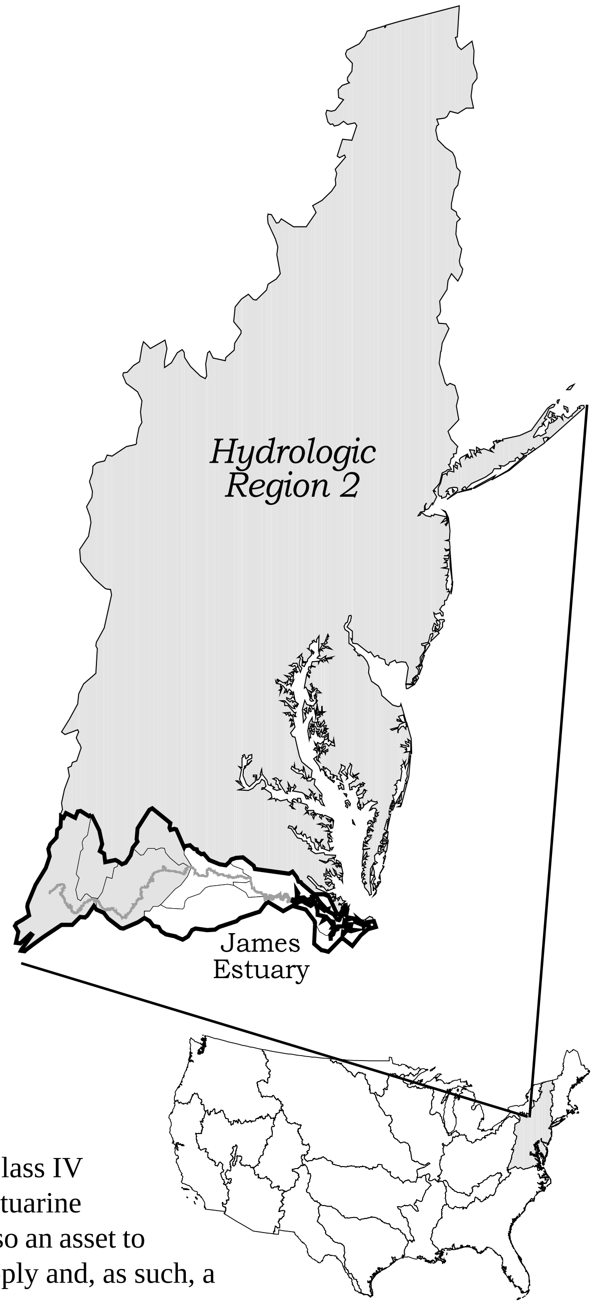


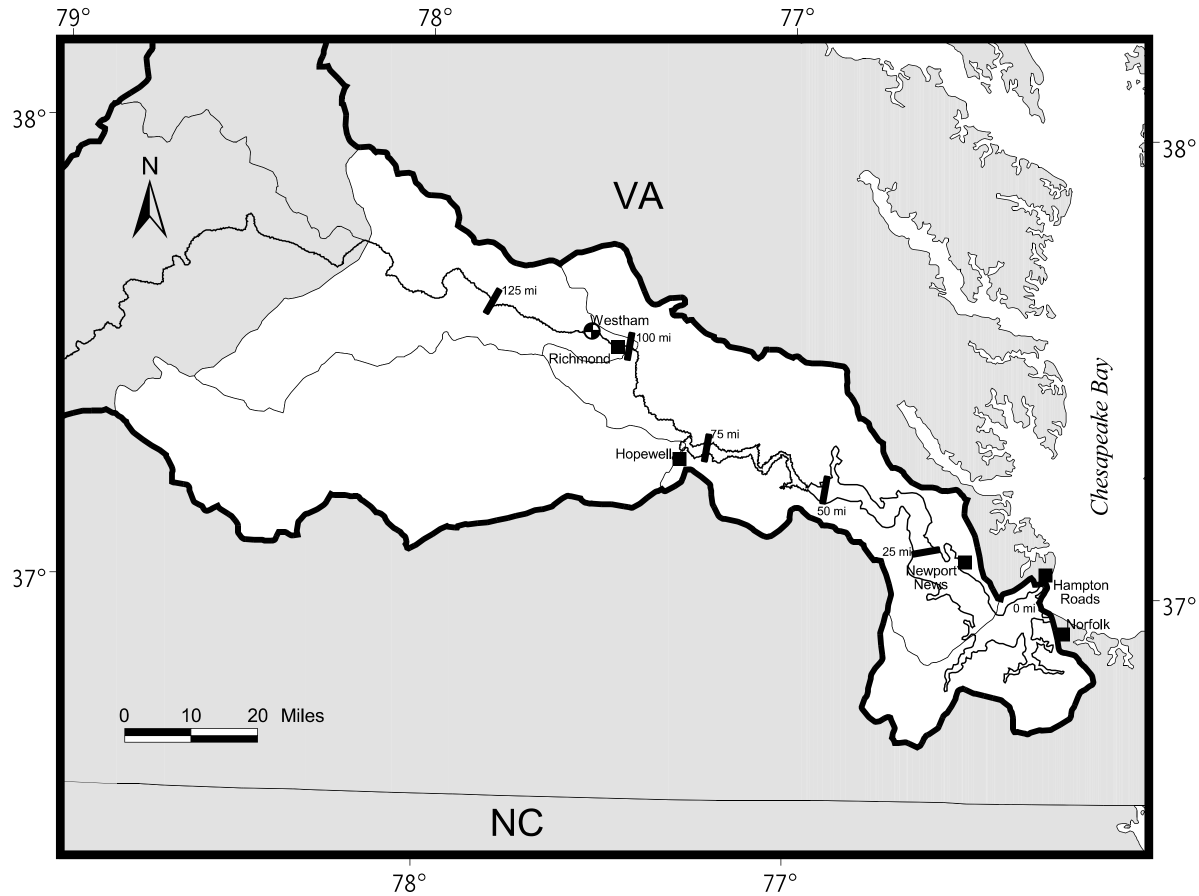
Figure 9-1
Hydrologic Region 2 and the James estuary watershed.

Physical Setting and Hydrology

The James River is a typical coastal plain estuary draining to the Chesapeake Bay. The variation of depth, cross-sectional area, and tidal velocity in the James River from Richmond to the Chesapeake Bay is significant. For example, the cross-sectional average depths vary from about 10 feet in areas with shallow side embayments to 25 to 30 feet in the deepwater channel. The river generally widens in the downstream direction, although natural constrictions occur at

Figure 9-2

Location map of the James River basin. River miles shown are distances from Chesapeake Bay at the mouth of the James River.



several locations. Cross-sectional area varies markedly, from the deep, narrow channel in the upstream section to broad, shallower profiles downstream.

Upstream freshwater flow to the study area is monitored at the USGS gaging station near Richmond, Virginia, on the James River. The freshwater flow to the James River is contributed by runoff from 6,758 square miles of woodland and agricultural areas upstream of the city of Richmond. A relatively small additional flow enters the study area via the Kanawha Canal, bypassing the USGS gage near Richmond. The combined average annual flow in the river at the gage is 6,946 cfs (1937-1998). A relatively small intervening drainage area provides a nominal increase in in-stream flow between Richmond and the confluence with the Appomattox River. Water is withdrawn from the James River for both municipal and industrial purposes and then returned to the river. Treatment is provided by all users except those who use the water solely for cooling purposes. Long-term interannual and mean monthly trends in streamflow for the James River near Richmond, Virginia, are shown in Figures 9-3 and 9-4.

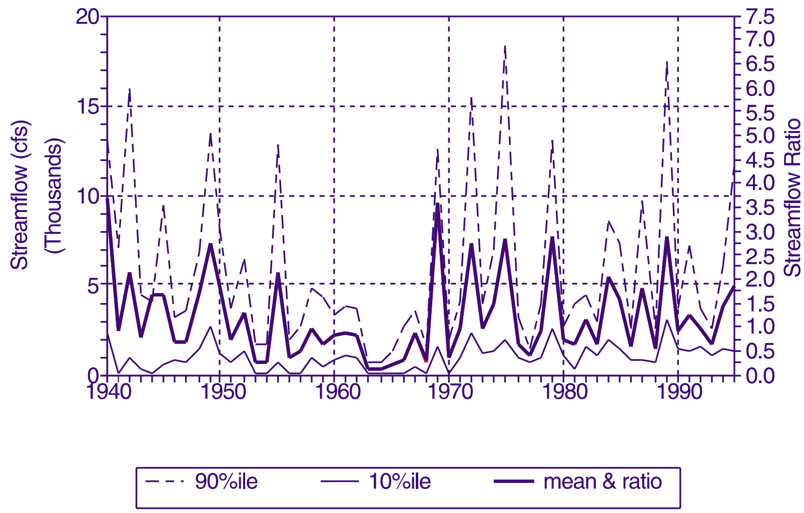


Figure 9-3

Trends of mean, 10th, and 90th percentile statistics computed for summer (July-September) streamflow for the James River (USGS Gage 02037500 near Richmond, Virginia).

Source: USGS, 1999.

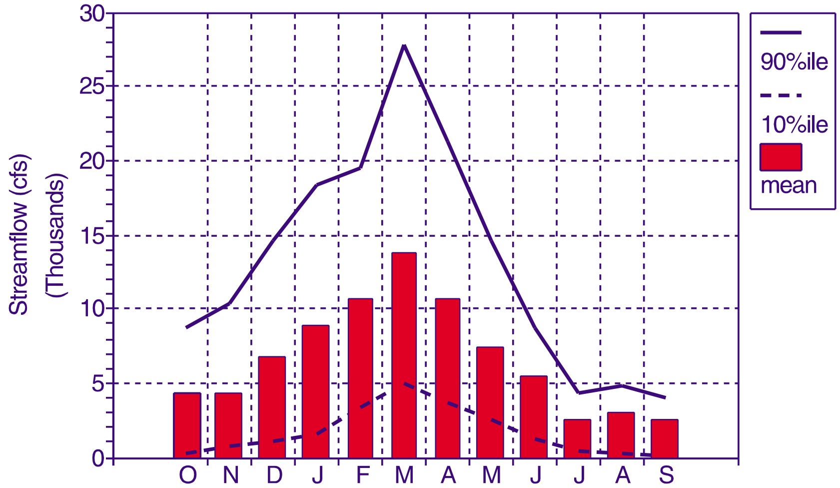


Figure 9-4

Monthly trends in streamflow for the James River. Monthly mean, 10th, and 90th percentile statistics computed for 1951-1980 (USGS Gage 02037500 near Richmond, Virginia).

Source: USGS, 1999.

Population Trends

The James estuary case study area includes a number of counties identified by the Office of Management and Budget as Metropolitan Statistical Areas (MSAs) or Primary Metropolitan Statistical Areas (PMSAs). Table 9-1 lists the MSAs and counties included in this case study. Figure 9-5 presents long-term population trends (1940-1996) for the counties listed in Table 9-1. From 1940 to 1996, the population in the James estuary case study area more than tripled (Forstall, 1995; USDOC, 1998).

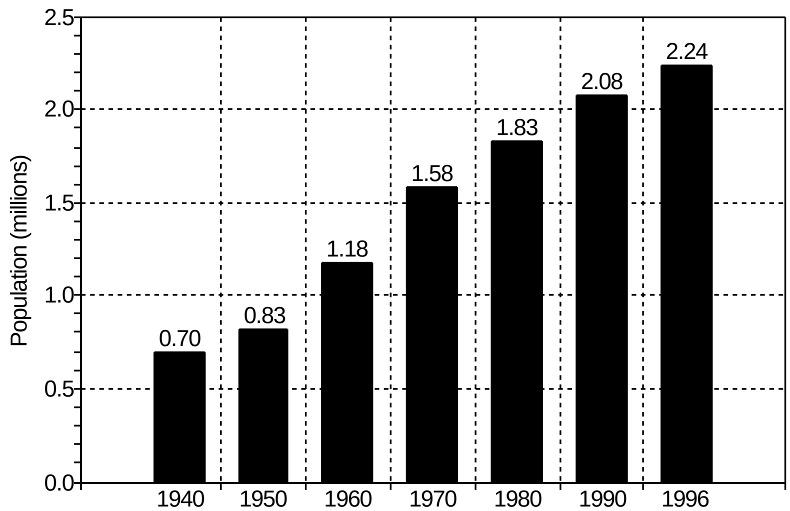
Table 9-1. Metropolitan Statistical Area (MSA) counties in the James estuary case study. *Source: OMB, 1999.*

Norfolk-Virginia Beach-Newport News, VA-NC MSA	*Richmond-Petersburg, VA MSA*
Currituck County, NC	Charles City County, VA
Gloucester County, VA	Chesterfield County, VA
Isle of Wight County, VA	Dinwiddie County, VA
James City County, VA	Goochland County, VA
Mathews County, VA	Hanover County, VA
York County, VA	New Kent County, VA
Chesapeake City, VA	Powhatan County, VA
Hampton City, VA	Prince George County, VA
Newport News City, VA	Colonial Heights City, VA
Norfolk City, VA	Hopewell City, VA
Poquoson City, VA	Petersburg City, VA
Portsmouth City, VA	Richmond City, VA
Suffolk City, VA	
Virginia Beach City, VA	
Williamsburg City, VA	

Figure 9-5

Long-term trends in population in the James estuary basin.

Sources: Forstall, 1995; USDOC, 1998.



Historical Water Quality Issues

The estuarine system starts near Richmond, where the fall line is located, and extends approximately 100 miles from the mouth of the river. The historical water quality concerns in the estuarine system have been dissolved oxygen and increased nutrient loads. DO is affected by the carbon and nitrogen components of the wastewater effluents. It is also influenced indirectly by the phosphorus content of these sources insofar as the latter stimulates phytoplankton growth.

In 1947 the 14-mile stretch of the James River east of Richmond was described as “dead.” In 1963 conditions had not improved despite growing public concern. The *Richmond News Leader* described the river as a sewer. After powerboat tour of the river, the editor described the river as green with algae, septic, and laden with dead and dying fish. Even the hardy catfish, which normally tolerates severely polluted waters, was observed gasping for its last breath. The only birds in sight were circling turkey vultures, attracted by the floating offal. At that time, the sewage collection system for Richmond was only partially operational and only 58 percent of the design flow of the city’s sewage treatment plant was being used. Raw sewage was being discharged into the James through Gillies Creek, and it seemed doubtful that the river would ever meet the minimum standard of 4.0 mg/L of dissolved oxygen required to permit recreational river uses (*Richmond News Leader*, 1963).

Legislative and Regulatory History

Concern over the severely degraded conditions in the James River prompted the General Assembly to establish the State Water Control Board (SWCB) in 1946. The Board used its authority to put pressure on the city of Richmond to expand its treatment facilities and on industries to cease their discharges into the river (*Richmond News Leader*, 1963). Although the city responded favorably and hopes were raised that the river could be fishable again within 10 years, a brief inspection of the river in 1963 revealed that the expectations of the Game and Inland Fisheries Commission had been overoptimistic. The river was as dead as it had been in 1947.

The most significant impetus for change came with the passage of the federal Clean Water Act in 1972. This legislation forced states and localities to clean up municipal discharges and provided federal and state money with which to do it. Richmond upgraded its sewage treatment plant in 1974 to remove as much as 80 percent of the suspended solids (secondary treatment) (*Richmond Times-Dispatch*, 1992). Later upgrades included a 500-million-gallon storm overflow basin in 1983, a $73 million filtering system in 1990, and an agreement in 1992 to spend $82 million for more improvements scheduled for completion in 1998 (*Richmond Times-Dispatch*, 1992).

Water supply and wastewater treatment facilities have been developing at a rate commensurate with growth in the James River basin over the past few decades. As a result, the James River, including the Appomattox River, has received increased quantities of treated effluent from both municipal and industrial sources. The Virginia SWCB realized the necessity of planning for waste treatment requirements many years ago. Between 1960 and 1962, several water quality studies were conducted to document the water quality conditions in the James River. These studies were among the earliest to quantitatively evaluate the natural assimilation capacity of the James River in the Hopewell and Richmond areas and to estimate the effect on stream quality of local industrial waste discharges.

Recognizing that proper planning must be implemented on a regional basis to protect the river system from impairment of its numerous desirable uses, SWCB entered into an agreement with the USEPA in 1971, under section 3(c) of the Federal Water Pollution Control Act of 1965, to study the James River. A principal outcome of this effort, completed in 1974, was the development of a James River ecosystem model by the Virginia Institute of Marine Science (VIMS). The SWCB used this model for wasteload allocations in the James River. Following the 3(c) study, the Richmond-Crater 208 study was funded and a second detailed water quality management model, the James Estuary Model (JEM), was developed for the upper James River estuary. This model was found to be inconsistent with the VIMS model, and a review of both models was conducted by HydroScience, Inc. The VIMS model was modified, and the revised James River model (JMSRV) was recalibrated for use in updating wasteload allocations (Hydroscience, 1980). The SWCB staff used the latter model to develop wasteload allocations, i.e., the Upper James River Wasteload Allocation Plan, in 1982 (SWCB, 1982).

Nutrient reduction has also been considered, and control measures have been implemented as part of the effort to clean up the Chesapeake Bay. The 1987 Virginia General Assembly took action to reduce nutrient enrichment by enacting a phosphate detergent ban. The next step was taken in March 1988 when the Virginia SWCB adopted the Policy for Nutrient-Enriched Waters and a water quality standard designating certain waters as nutrient-enriched. Under the policy, municipal and industrial wastewater treatment plants with flows higher than 1 mgd are required to remove phosphorus to meet a 2-mg/L limit. Facilities are given up to 3 years to complete plant modifications to meet this requirement.

Impact of Wastewater Treatment: Pollutant Loading and Water Quality Trends

Pollutant loads from POTWs have been reduced significantly over the past two decades. In 1971 a large number of the municipal wastewater treatment plants provided primary treatment. By 1984 there were more than 20 major point source (municipal and industrial) discharges in the James River estuary from Richmond to the mouth of the Chesapeake Bay. Table 9-2 lists the major municipal and industrial treatment facilities discharging to the James River during 1983. Figure 9-6 illustrates the locations of these point sources. Some of the municipal facilities were consolidated to form regional treatment plants. In the early 1980s all POTWs achieved secondary treatment levels except the Lambert's Point plant, which was considered at an advanced primary level (with phosphorus removal). Since the early 1980s, waste load allocation studies have been prepared to recommend further reductions of the BOD_5 loads in the upper estuary. Some of

Table 9-2. Major point source loads to the James estuary in September 1983. *Source: Lung and Testerman, 1989.*

Discharger	River Mile[1]	Flow (mgd)	CBOD$_5$ (lb/day)
Richmond	97.8	56.5	4512
DuPont	92.7	6.9	202
Falling Creek	92.2	7.2	714
Proctors Creek	86.9	3.1	2602
Reynolds Metals	86.9	0.1	1
VEPCO	85.7	0.09	0
American Tobacco	81.5	0.07	54.8
ICI	80.6	0.06	8.9
Philip Morris	79.8	0.0	63.2
Allied-Chester	78.5		3959
Allied-Hopewell	77.2	0.0	4909
Stone Container	76.8	13.5	
Hopewell	76.1	35.8	16200
Williamsburg		9.2	229
James River		12.5	436
Boat Harbor		16.1	410
Nansemond		6.8	770
Army Base		12.1	413
Lambert's Points		20.2	21893
Petersburg[2]	88.9		

[1] Distance from the Chesapeake Bay.
[2] 10.8 miles from the James River

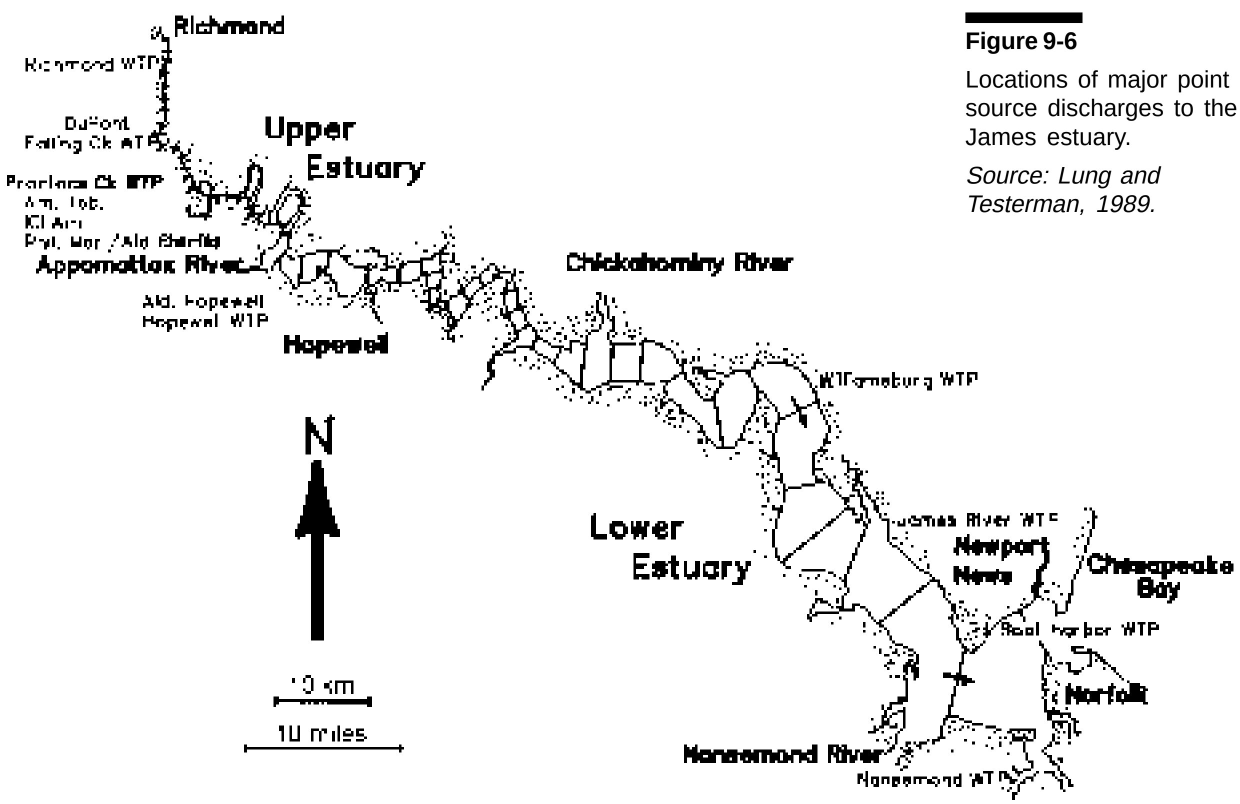


Figure 9-6

Locations of major point source discharges to the James estuary.

Source: Lung and Testerman, 1989.

Table 9-3. Effect of phosphate detergent ban: Hampton Roads Sanitation District. *Source: Lung and Testerman, 1989.*

Time Period	Influent (mg/L)	Effluent (mg/L)
Pre-Ban	7.4	5.3
Transition	5.6	3.7
Post-Ban	4.9	2.5
Reduction	34%	53%

them, such as those in the Hampton Roads Sanitation District, achieved BOD_5 concentrations in the effluent much lower than 30 mg/L.

A study by the Virginia SWCB showed that the phosphate detergent ban has resulted in reductions of total phosphorus concentrations of 34 percent for POTW influent and 50 percent for effluent (SWCB, 1990). The SWCB's analysis was based on the data collected from the POTWs operated in the Hampton Roads Sanitation District, which operates nine POTWs in the James River basin. The total phosphorus concentrations measured during different periods of the study are shown in Table 9-3.

It should be pointed out that the analysis shown in Table 9-3 was based on the POTWs that did not have phosphorus removal. The phosphate detergent ban would have no effect on the effluent phosphorus concentration from the POTWs that remove phosphorus. Eventually, when the POTWs remove phosphorus to meet the 2-mg/L requirement, the ban will reduce the costs of phosphorus removal by reducing the influent concentrations.

The upstream boundaries and tributaries the watershed of the estuary account for approximately 94 percent of the drainage area measured below the confluence of the James and Chickahominy rivers. The area adjacent to the Appomattox and James rivers below Richmond is thus a small fraction of the total area drained by this system. Runoff from the contiguous drainage area during the low-flow summer months represents a small fraction of the total river flow and has a negligible effect on the water quality in the watershed. The importance of the upstream pollutant loads was reported by HydroQual Inc. (1986). For example, in the James, the upstream ultimate BOD load is larger than any point source load, and the nitrogenous BOD (NBOD) is nearly equal in magnitude to several of the largest point source inputs. Similarly, the Appomattox River boundary load is significant relative to the Petersburg wastewater treatment plant discharge, the only significant point source input to this river. Further, the three point source inputs, the Richmond and Hopewell treatment plants and Allied-Hopewell, account for the major portion of the point source loads to the James. The nonpoint source runoff load was shown to be relatively small in comparison to the other inputs to the system (HydroQual, Inc., 1986).

It should be pointed out that CSO loads might be significant inputs to the river system during wet weather conditions and might also be a factor in the sediment interactions. In view of the purpose of this study, CSOs are not included in this analysis. The CSO impacts are indirectly incorporated into the modeling analysis to the degree that they are a component in the sediment oxygen demand rates determined by HydroQual (1986).

Figure 9-7 shows historical data of DO concentrations in the James estuary. The June 1971 survey shows that the river reach from Richmond to Hopewell was dominated by the waste discharges from and near Richmond. During that survey, the river was under a moderately high temperature and high flow. Consequently, the DO sag was carried downstream far enough (about 35 miles from Richmond) to merge with the Hopewell area discharges. Downstream from Hopewell, the DO concentrations started a slow recovery. In the lower estuary from Mulberry Island (river mile 27) to Old Point Comfort (milepoint 0), there were a number of large waste discharges. As a result of the strength of the tidal

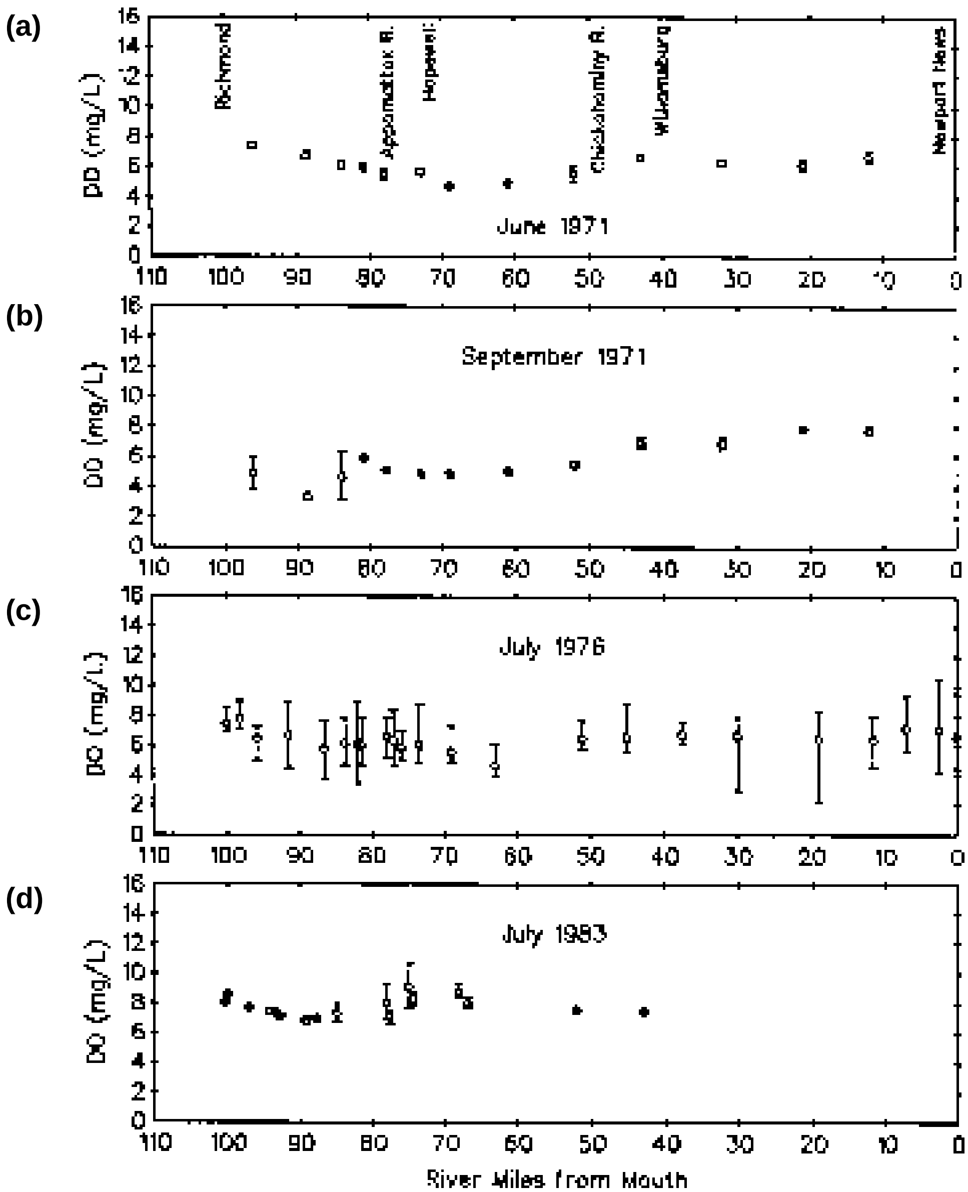


Figure 9-7

Spatial distribution of DO for the James estuary (a) June 1971, (b) September 1971, (c) July 1976, and (d) July 1983.

Sources: HydroQual, 1986; Lung, 1986; Lung and Testerman, 1989.

action combined with the massive amount of dilution water available, a rather steady DO level was measured. The DO levels seldom fell below 5.5 mg/L under the worst conditions, and the depression of DO due to waste stabilization by biological oxidation was usually less than 1 mg/L (Engineering Science, 1974).

The second survey in Figure 9-7 was conducted in September 1971, showing even lower DO concentrations below Richmond, compared with the data from the June 1971 survey. The DO sag was below 4 mg/L near milepoint 89, which was followed by a slow recovery. Also shown in Figure 9-7 is the DO profile measured in July 1976. The DO sag level (below Richmond) improved slightly from the 1971 condition although the sag was still below 5 mg/L. A mild recovery occurred until the wastes from the Hopewell area entered the river and depressed the DO concentration again, resulting in a second DO sag in the river. Such a two-sag DO profile has been consistently observed since the late 1970s. The low DO gradually increased downstream for a full recovery.

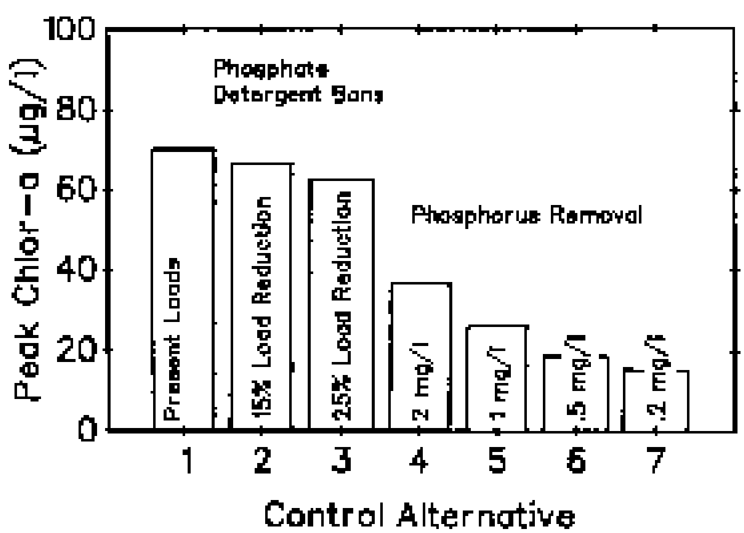
The DO condition observed in July 1983 is also presented in Figure 9-7. With continuing treatment upgrades beyond the secondary treatment for carbon removal, the DO condition in the James estuary continued to improve in the 1980s. The data indicate that the minimum DO level was above 6 mg/L in September 1983, a sign of continuing improvement of the water quality. The impact from the Richmond area discharges has been significantly reduced following the treatment plant upgrades.

Although the reduction of BOD_5 loads from the POTWs was measured in the last 20 years, no appreciable reduction of nutrient loads was detected until the phosphate detergent ban in 1988. Prior to the Virginia phosphate detergent ban, Lung (1986) conducted a modeling study assessing the water quality benefit of point source phosphorus control in the James River basin. The model results are summarized in Figure 9-8, showing the peak phytoplankton chlorophyll levels predicted in the upper James estuary for various control alternatives ranging from a phosphate detergent ban to phosphorus removal. The model suggests that the reduction of chlorophyll in the water column due to the phosphate detergent ban would be minimal while phosphorus removal at POTWs would offer reasonable reductions in phytoplankton biomass in the upper estuary.

Figure 9-8

Projected impact of point source phosphorus controls.

Source: Lung and Testerman, 1989.



Evaluation of Water Quality Benefits Following Treatment Plant Upgrades

From a policy and planning perspective, the central question in water pollution control is simply *Would water quality standards be attained if primary treatment levels were considered acceptable?* In addition to the qualitative assessment of historical data, water quality models can provide a quantitative approach to judge improvements in water quality achieved as a result of upgrades in wastewater treatment. The James River Model (JMSRV), originally developed by Hydroscience (1980) and subsequently enhanced by HydroQual (1986), Lung (1986), and Lung and Testerman (1989), and calibrated using data for September 1983 conditions (Figure 9-9), has been used to demonstrate the water quality benefits attained by the secondary treatment requirement of the 1972 CWA

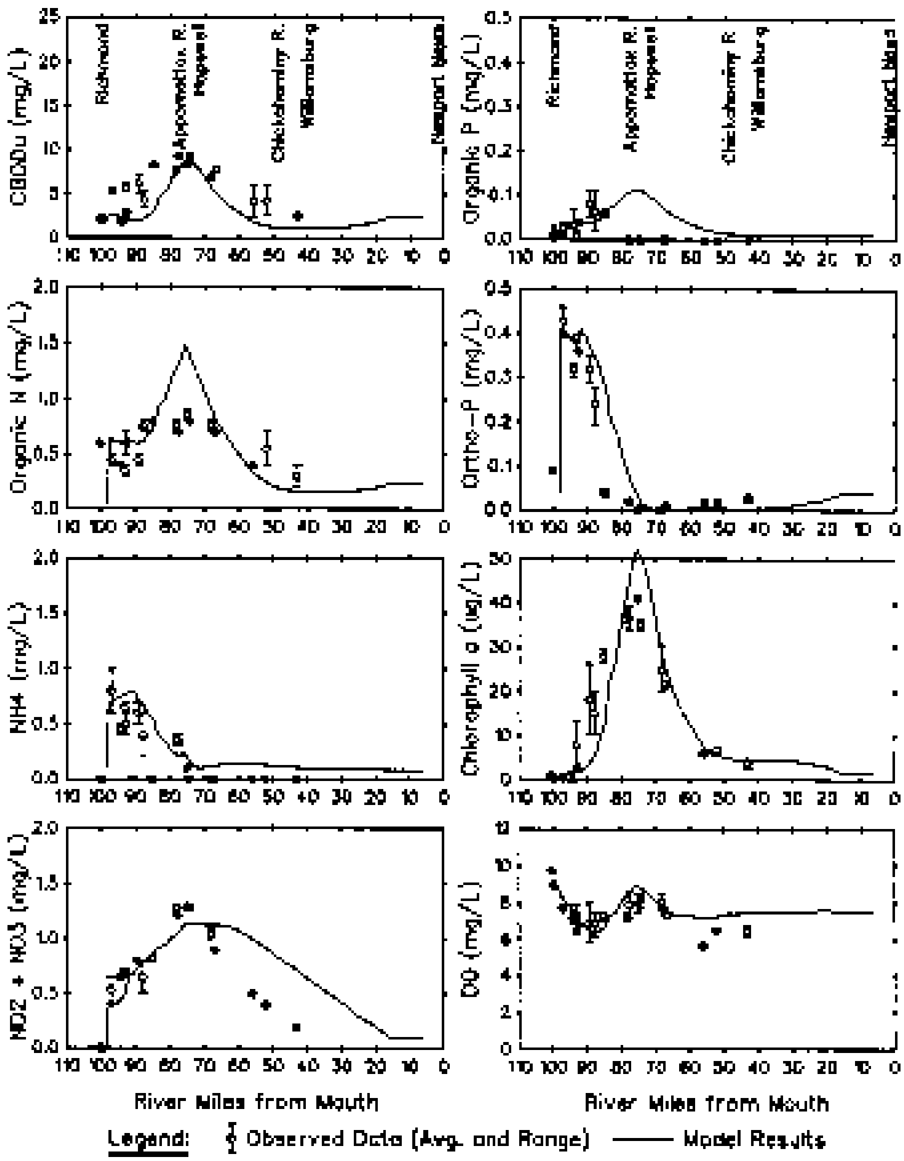


Figure 9-9

James River model calibrations for September 1983.

Source: Lung, 1991.

(Lung, 1991). Using the model, existing population and wastewater flow data (ca. 1983) were used to compare water quality for summer low-flow and 7Q10 low-flow conditions simulated with three management scenarios: (1) primary effluent, (2) secondary effluent, and (3) existing wastewater loading. Water quality conditions for these alternatives were simulated using freshwater and wastewater flow data for 1983, a year characterized by 66 percent of the summer average flow (see Figure 9-3) of the James River (Figure 9-10).

Using the primary effluent assumption, under summer low-flow conditions, water quality is noticeably deteriorated in comparison to the 1983 calibration results. DO concentrations downstream of Richmond (RM 90) are computed to be near zero under the primary scenario. Using the secondary assumption, the significant reduction in BOD_5 loading significantly improves DO between Richmond and Hopewell, Virginia. In comparison to the primary scenario, minimum

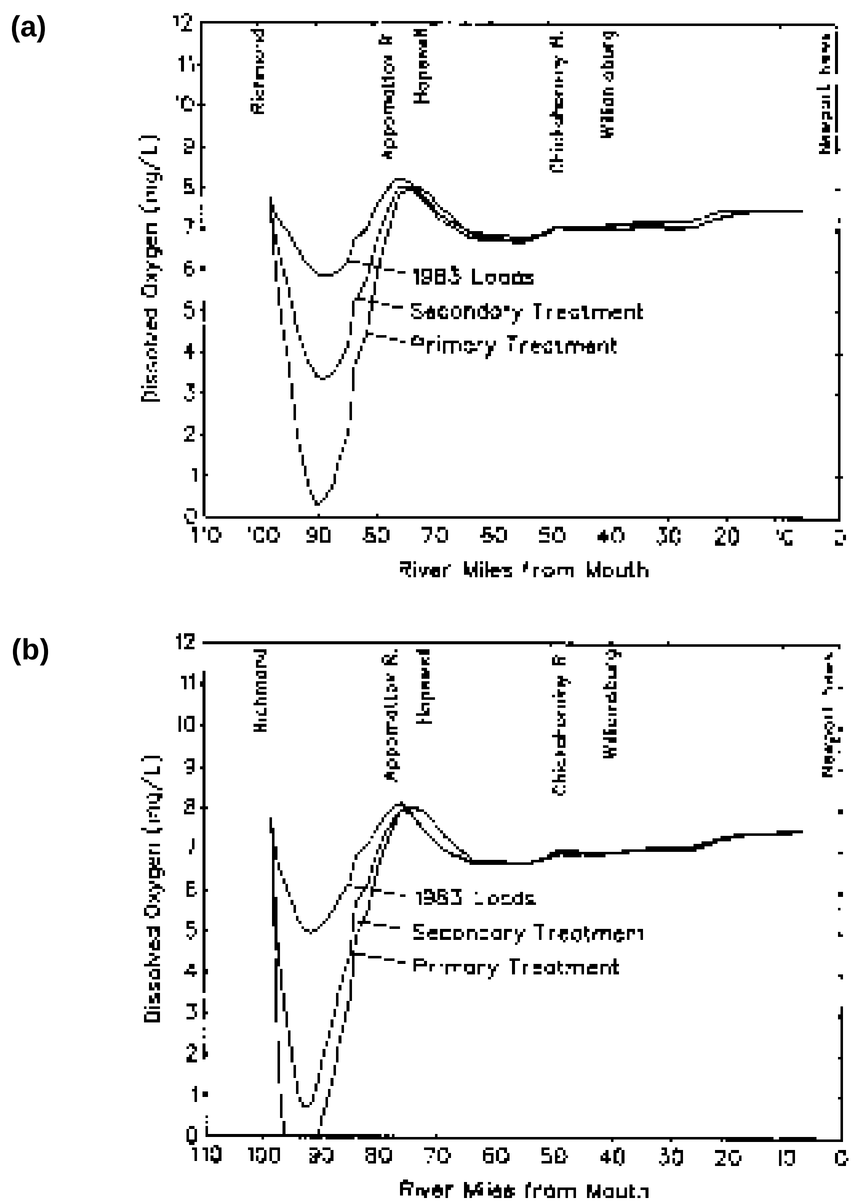


Figure 9-10

Comparison of simulated impact of primary, secondary and existing 1983 effluent levels on DO: (a) summer 1983 conditions and (b) 7Q10 low-flow conditions.

Source: Lung, 1991.

monthly averaged oxygen levels increase to almost 3.5 mg/L from less than 0.5 mg/L under the secondary effluent scenario. As shown with both observed data (Figure 9-9) and state-of-the-art model simulations (Figure 9-10), the implementation of secondary and better treatment has resulted in significant improvements in the DO status of the estuary.

As demonstrated with the model, better-than-secondary treatment is required to achieve compliance with the water quality standard of 5 mg/L under extreme 7Q10 low-flow conditions (Figure 9-10) for DO downstream of Richmond. In contrast to the 1950s and 1960s, the occurrence of low-oxygen conditions has been virtually eliminated within the upper James River estuary. Additional improvements in water quality, in terms of reduced algal biomass and still greater improvements in DO levels, have been achieved as a result of advanced secondary levels of wastewater treatment for the Upper James River.

Impact of Wastewater Treatment: Recreational and Living Resources Trends

Upgrades of wastewater treatment plants to secondary treatment in the 1970s and continued commitment to water quality-based pollution controls throughout the 1980s and 1990s have achieved a dramatic recovery for the James River. Instead of turkey vultures, residents of Richmond currently gaze at blue herons, bald eagles, and ospreys as they circle overhead (Epes, 1992). Although passage of the Clean Water Act in 1972 was the most significant factor contributing to the comeback of the James, other factors contributing to improvements in wildlife habitat included the creation of a flood control reservoir in the early 1980s to stabilize flow, the ban of the insecticide DDT, and floods and hurricanes in the 1960s and 1970s.

The ban on DDT allowed certain birds affected by egg shell thinning, including eagles and ospreys, to recover. The floods and hurricanes contributed to habitat improvement by punching holes in several of the dams in the river, allowing migrating fish to pass through once more (Epes, 1992). Those holes and subsequent man-made fish ladders have allowed fish to swim farther upstream to spawn again.

Above the falls, the return of smallmouth bass has made the upper James one of the best smallmouth bass fisheries in the country. Below Richmond, abundant largemouth bass attract the national Bassmasters fishing tournaments. Striped bass, an anadromous (saltwater-to-freshwater migrating) fish, has returned to the James due in part to a state harvesting moratorium in effect for several years in the Chesapeake Bay. In fact, a 25-pound striped bass was caught in 1992 near Williams Dam in Richmond (Epes, 1992).

Fish-eating birds have also recently returned to the James. In the 1970s there were no bald eagles or ospreys nesting on the James River. In 1992 three pairs of bald eagles and six pairs of ospreys had reclaimed their historical nesting sites on the James (Bradshaw, 1992). Great blue herons boast about 200 pairs (Bradshaw, 1992). Birds began to return in the mid-1980s (Table 9-3). Cattle egrets and double-crested cormorants extended their ranges to colonize the James possibly due to reduction in available habitat elsewhere. In 1992, there were about 250 pairs of each overwintering in the region from Richmond to the Benjamin Harris bridge (Bradshaw, 1992). Cattle egrets eat reptiles and eels, and double-crested cormorants eat fish. These birds are no doubt responding to the increase in the stream quality for fish and other aquatic life now that organic and nutrient loads to the James have been controlled.

Summary and Conclusions

An analysis of the existing water quality data for the James River estuary has been conducted to document the historical changes in waste loads and the water quality improvement in the estuary from 1971 to the mid-1990s. The latest water quality model for the upper James estuary was modified to include the lower portion of the estuary. This modified model was calibrated and verified using three sets of water quality data. Finally, the verified model was used to evaluate the water quality improvement due to the treatment upgrades from primary to secondary at the POTWs. Altogether, six simulation scenarios, incorporating different ambient environmental conditions and waste load levels, were developed for evaluation.

The analysis of POTW waste loads indicated significant reduction of BOD_5 discharged into the James estuary starting in the early 1970s. By the mid-1980s, many POTWs had achieved high degrees of carbon removal with treatment levels beyond secondary. Nutrient reduction did not start until 1988, when the phosphate detergent ban became effective.

A review of the historical water quality data showed the improvement of DO conditions in the James estuary from a DO sag of much lower than 5 mg/L in 1971 to levels consistently above 5 mg/L in the 1980s. Nutrient concentrations in the water column of the James estuary have remained quite stable over the past 20 years. The model results showed a clear, progressive rise in DO levels in the estuary from primary treatment to secondary treatment, and to treatment beyond secondary at the POTWs. Based on the analyses of historical waste load data, water quality data, and model results, it can be concluded that the treatment upgrades from primary to secondary and better levels of treatment at POTWs provided significant water quality improvement in the James River basin. With the cleanup of the James River, visitors to Richmond, Virginia, can enjoy a riverboat dinner cruise or a stroll along the refurbished 2-mile canal walk. More adventurous visitors can challenge themselves by rafting and kayaking on the only Class IV white water located in an urban river in the country (McCulley, 1999). Birds and fish are also making a remarkable recovery in the James River basin in response to water quality improvements.

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